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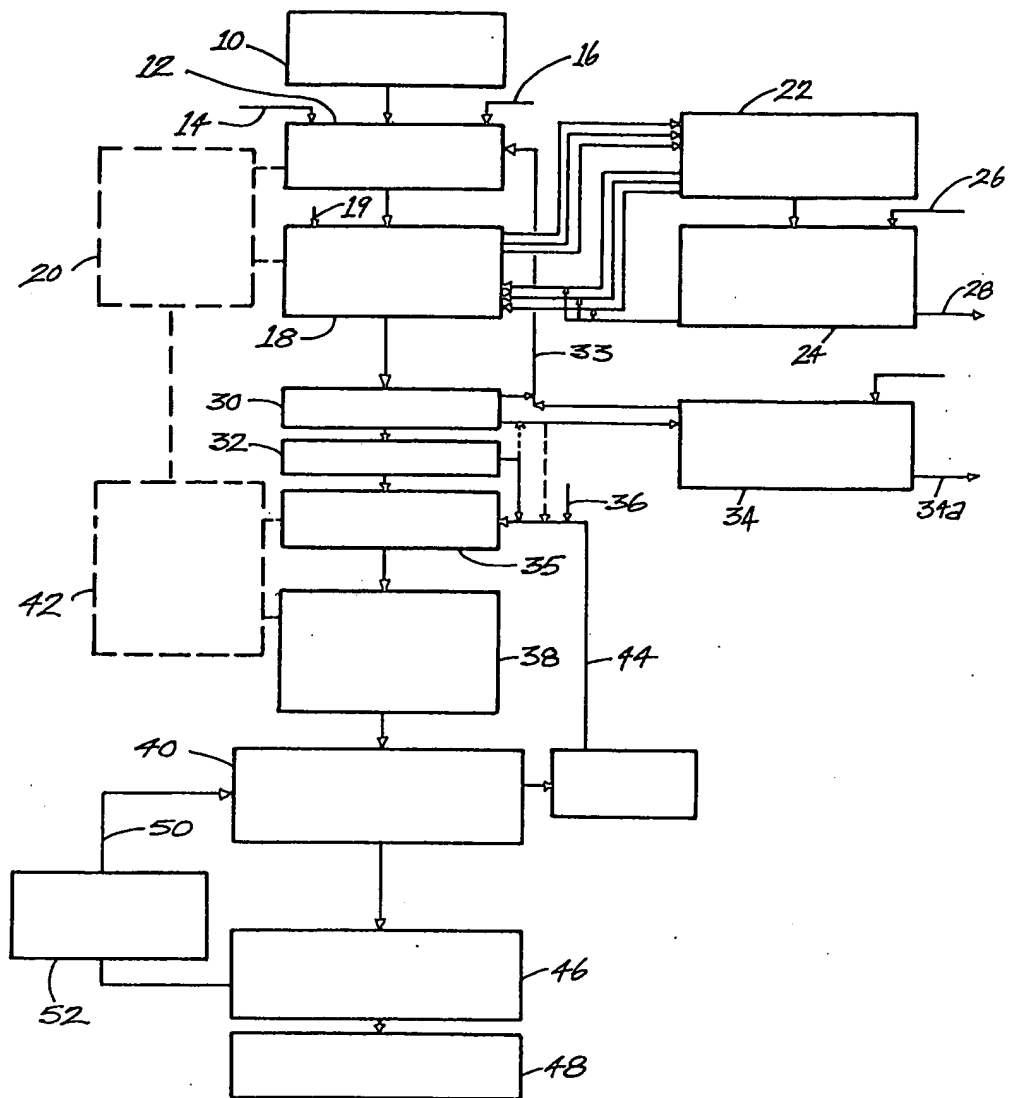
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(54) **Precious metal extraction**

(57) The present invention relates to a process for the extraction of gold and/or silver from a particulate auriferous or argentiferous sulphide containing substrate which comprises contacting the substrate with an acidic aqueous leach medium containing an aerobic sulphide-oxidizing bacteria so as to oxidize at least a portion of the sulphide to sulphate, and then contacting the oxidized substrate with a chemical reagent in an aqueous medium so as to dissolve gold and silver present in the oxidized substrate.

Typically, the chemical reagent is thiourea, chlorine, hypochlorite, chloride, thiosulphate or thiocyanate or a combination thereof.



SPECIFICATION

Precious metal extraction

- 5 This invention relates to a process for extraction of gold and silver from sulphide containing materials such as ores, concentrates and tailings. In particular, the process is a combination of microbial oxidation with leaching of gold and silver in acid solution environments. 5
- This invention relates to a process for extraction of gold and silver from sulphide containing materials such as ores, concentrates and tailings. In particular, the process is a combination of microbial oxidation with leaching of gold and silver in acid solution environments. 10
- 10 The leaching of metals from sulphide-containing materials by bacteria, such as *Thiobacillus ferrooxidans*, is well known and gained acceptance in particular applications such as extraction of copper or uranium from low-grade ores.
- The bacterial leaching by *T. ferrooxidans* releases the base metals from sulphides into solution, forming mostly soluble metal sulphates and oxidizes the sulphur chemically bound in the crystal-line structure from sulphide to sulphate, thereby destroying the crystal lattice of the mineral. Gold and silver values are often associated with sulphides such as pyrite, arsenopyrite, stibnite, tetrahedrite, sphalerite and galena. Sulphide orebodies represent a significant future source of gold and silver but their treatment poses some technical problems. Many of these orebodies are regarded as being "refractory", because of the mineralogical form of the gold and silver. The precious metals, in these occurrences, are often not amenable to solubilization by direct leaching, for instance, in cyanide solution or at times the process is not feasible due to prohibitive cost of treatment. These ores generally require a preliminary oxidation step which may involve high temperatures and pressures or use of expensive chemical oxidants. 15
- 20 In the past, the refractory ores have generally been subjected to a flotation treatment to concentrate the sulphides followed by roasting to liberate the gold before separate or combined cyanidation of the calcine and tailings. The high capital costs and the extensive emission control from waste gases suggest that this route will not always be commercially viable. Pollution control problems are compounded when the concentrates contain arsenic, selenium and mercury which commonly accompany gold mineralizations. Pressure oxidation of refractory sulphide concentrates has also been practised under high pressures, 1500–2000kPa, at about 180°C, to break down the sulphides and liberate the gold prior to cyanidation. 20
- 25 Recovery of gold and silver by cyanidation is one of the most widely used industrial processes. It operates in alkaline media, at pH values greater than 7, requires oxygen from air as oxidant and forms an anionic complex of gold, $\text{Au}(\text{CN})_2^-$. A conceptual drawback of bacterial leaching, of refractory sulphides followed by cyanidation for extraction of gold and silver is that subsequent cyanide leaching is only possible after neutralizing the sulphuric acid generated in the bacterial leaching step. Careful washing out and neutralizing the acid adhering to bacterial leach residue is a prerequisite to avoid evolution of toxic hydrocyanic acid from the cyanide. These shortcomings are also prevalent when roasting and pressure oxidation methods are used as a preliminary oxidation route. In certain practical situations, such as heat-leaching and in-situ leaching these washing and neutralizing operations may be present extreme difficulties. Another disadvantage of use of cyanide is that, in certain environmentally sensitive locations, stringent regulations on mine waste disposal and discharge/seepage water quality may prohibit use of this toxic lixiviant. Furthermore, in recovery of gold and silver from alkaline cyanide solution by adsorption onto activated carbon, fouling of carbon surfaces occur due mainly to calcium and magnesium ions and solubilized base metals such as copper and nickel. 25
- 30 Despite these inherent disadvantages, use of bacteria to oxidize sulphides prior to cyanidation has previously been conceptually proposed, demonstrated on a bench and mini-plant scale and published in the literature. 30
- 35 The present invention provides a process for extraction of gold and silver from auriferous and argentiferous sulphide ores, concentrates or tailings in which the use of extreme processing conditions to liberate the precious metal and cyanide to extract the precious metal are avoided. In accordance with one aspect of the present invention there is provided a process for the extraction of gold and/or silver from a particulate auriferous or argentiferous sulphide containing substrate which comprises contacting the substrate with an acidic aqueous medium containing an aerobic sulphide-oxidizing bacteria so as to oxidize at least a portion of the sulphide to sulphate, and then contacting the oxidized substrate with a chemical reagent in an aqueous acid medium so as to dissolve gold and silver present in the oxidized substrate. The process of the present invention can be conducted in a series of cascading or batch agitated leach systems or using static leach systems such as so-called heap leaching or in-situ leaching. Agitation in tanks can be provided by motor-driven impellers or air sparging. Heap leaching may involve contacting the bacterial solution with broken ore having a particle size less than 30mm. Fine material can be agglomerated if it interferes with solution flow. The bacterial leach solution is typically recirculated to the top of the heap preferably for a period in the range from 1 to 8 months. 35
- 40 45 50 55 60 65

After recycling is stopped, the heap is typically drained to a bacterial leach sump. The chemical reagent solution may then be applied to the top of the heap. The chemical reagent is collected after it has passed through the heap and it may then be passed through a particulate collecting substrate such as carbon or resin or alternatively contacted with iron or aluminium for cementation of the gold.

The stripped chemical reagent solution is then recirculated to the top of the heap after addition of "make-up" chemical reagent, and the process is continued as required.

The process of the present invention typically involves contacting an adapted strain of bacteria in a slurry suspension at a pH preferably not less than 0.7 in sulphuric acid.

10 The oxidizing bacteria is an aerobic strain which may contain *T. ferrooxidans* and/or *T. thiooxidans* in a mixed culture. The bacteria is preferably predominantly autotrophic although it preferably can also grow heterotrophically on organic material.

The bacteria may be adapted by being subjected to progressively increasing levels of dissolved metals expected to be found under practical conditions of operation. The adaptation procedure subjects the bacteria to a selection process in which only the micro-organisms resistant to process conditions thrive. The temperature of the process is generally in the range from 5 to 40°C and most preferably from 27 to 37°C. Some forms of *T. ferrooxidans* or *Sulfolobus* may function at moderate or extreme temperatures and the process of invention may be carried out at temperatures up to the maximum temperature at which the particular micro-organism is viable. The particle size of the particulate substrate material is preferably less than 500 microns, more preferably less than 74 microns.

The acidic aqueous leach medium containing the substrate preferably contains initially from 10 to 40% by weight solids. Further, the leach medium containing suspended solids may be aerated to supply oxygen and optionally carbon dioxide for the bacterial leaching process.

25 The acidic aqueous medium preferably has a pH in the range from 1.3 to 2.7 in the bacterial leaching circuit. As the sulphide of the substrate material is oxidized to form sulphuric acid along a series of interconnected tanks, the leach medium can get progressively more acidic. Therefore, inter-stage neutralization of the leach suspension may be required to maintain pH within the desired range.

30 This may be accomplished by "bleeding" a stream of slurry to an external system of solid/liquid separators, typically settling tanks and/or hydrocyclones. The liquor is removed from the settled solids and transferred to neutralization circuit. Partial neutralization may be carried out in two stages at a pH value up to 4.0 but preferably between 2.75 and 2.95 by addition of alkaline material, typically limestone, slaked lime or sodium hydroxide. The molar ratio of iron to arsenic in their highest valency states i.e. Fe^{+3} to As^{+5} should be preferably not less than 4. If desired, bacterially oxidized ferric sulphate can be added to the first stage of neutralization to yield an environmentally acceptable precipitate. The precipitate obtained in the first neutralization stage contains predominantly jarosites and arsenates, whereas gypsum predominates in the second stage precipitate.

40 Both of these precipitates are discarded in an environmentally acceptable form.

The partially neutralized prior liquor and the solids from the separators are transferred to the next stage of bacterial leaching.

This partial neutralization can be carried out either on a continuous or an intermittent basis depending on process slurry requirements. The process requirements could be such that partial neutralization may need to be carried out only in the initial stages of the bacterial leaching circuit.

45 In commercial practice, projected heat balances indicate that cooling of the bacterial leach slurry will be required. The amount of cooling required is essentially controlled by kinetics of sulphide oxidation, amount of sulphide present in the substrate material and the rate of heat losses through evaporation or tank surface. It is envisaged that the low-quality heat obtained from this source can be used to increase the temperature of the slurry in the gold extraction circuit where chemical reagents such as thiourea, chlorine, hypochlorite chloride thiosulphate and thiocyanate or a combination of these reagents can be used to solubilize gold and silver in an acid leach medium. The preferred thiosulphate is the ammonium salt whilst the preferred thiocyanate is also the ammonium compound. However, sodium thiosulphate and thiocyanate are also particularly useful in the present invention.

55 The significance of recovery of low-quality heat lies in that not only does it maintain the temperature of the bacterial process within the defined range but also improves the rate of extraction of gold and silver by affording the chemical extraction stage to be carried out at temperatures above ambient, typically up to 70°C. This does not preclude use of ambient temperature for leaching.

60 The low-quality heat can also be used to accelerate the desorption of dissolved gold and silver particulate matrices such as activated carbon or strongly acidic cation ion exchange resins. Furthermore, the mass of the substrate in the bacterial leaching solution decreases rapidly along a cascade of leach tanks, as the sulphides are continuously removed through oxidation. Typically, the mass is reduced by up to 70%.

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The oxidation of sulphides by bacteria provides two main components necessary for extraction of gold and silver from the bacterial leach residues as follows.

- (1) Acid conditions which provide a stable environment for chemical species required for extraction of gold and silver. More specifically, if thiourea is used as the lixiviant then the pH is not to be greater than 2.0, if, however, chlorine or thiousulphate or hypochlorite or chlorides are used the pH is to be not more than 4.0 and preferably lies between 0.7 and 3.5 depending on vapour pressure than can be tolerated in the chemical extraction system. Lower pH values form more free Cl_2 and therefore require enclosed extraction systems to handle the corrosive gas safely. Chlorides are then preferred lixiviant for gold in regions where highly saline waters are commonly encountered such as in the Goldfields of Western Australia. As the sulphides are oxidized at the bacterial leaching stage, the consumption of chlorides are greatly reduced during gold extraction. Thiocyanates can be used below pH 7.0 preferably between pH 2.0 and 7.0. A combination of thiocyanate and thiourea can also be used with success in certain mineralizations.
- (ii) the bacterial leach medium can conveniently have all the above chemical reagents dissolved in it to extract gold and silver. For example, ferric ion formed by bacterial oxidation of iron-bearing sulphides in turn oxidizes the thiourea to formamide disulphide. The disulphide may disproportionate to yield thiourea and a sulphinic compound. The sulphinic compound may irreversibly decompose to cyanide and elemental sulphur. The elemental sulphur generated in this way is very fine and forms a protective coating reducing the tendency of thiourea and formamide disulphide to dissolve the precious metals. The presence of bacterial leaching medium can reduce this precipitation and can also oxidize the elemental sulphur.

The accompanying drawing is a flow diagram of a typical process according to the present invention.

- The drawing shows a concentrate feeder 10 arranged to receive ore concentrate in ground, particulate form which is passed to a conditioner tank 12. The conditioner tank is provided with means for feeding in air and nutrients through lines 14 and 16 respectively.

- The conditioned material is then fed to continuous bio-oxidation tanks 18 which is provided with an air feed 19. A heat exchanger is connected to the tanks 18 and the conditioner 12 so as to cool or heat the system as required and hence maintain the temperature between the defined range. The excess low-quality heat is transferred to tank 35 and tank 38 via heat exchanger 42 where applicable. Further, means is provided for bleeding of slurry from the tanks 18 and feeding it to settling tanks 22. The liquor from the settling tanks 22 is fed to a partial neutralizer tank 24 into which alkaline material is fed through a line 26. Precipitated material is withdrawn through a line 28. The settled solids and partially neutralized liquor are returned to the tanks 18.

- The biooxidized slurry from tanks 18 is fed to a thickener 30. A partial overflow liquor from the thickener, containing bacteria for recycle to the conditioning tank 12, is connected to a line 33 through which partially neutralized process liquor is also returned to the bacterial leaching circuit. The majority of the overflow liquor from the thickener 30 is also connected to a neutralizer 34 in which the liquid to be returned through the line 33 can be first partially neutralized and then totally neutralized for disposal. Precipitated material can be withdrawn through a line 34a.

- The thickened slurry is passed to a filter 32 in which a substantial proportion of liquid is removed from the slurry and a filter cake is produced. The filtered material is then passed to a conditioner tank 35 in which thiourea solution is introduced through a line 36. If desired, liquid from the filtration stage can be fed into the neutralizer 34, but it is usually dosed into the thiourea feed. Further overflow from the thickener may be dosed into the thiourea feed where necessary, on adjustment of redox potential of solution.

- The material from the conditioner tank 35 is then fed to extraction tanks 38 in which gold or silver is dissolved. The material is then fed to an adsorption tank 40 in which the dissolved gold or silver is adsorbed onto carbon or resin. An Eh control and heat exchanger 42 is provided for the tanks 35 and 38.

- A line 44 is provided to recycle solution from the adsorption tank 40 to the thiourea feed. The system further includes a desorption tank 46 in which dissolved precious metal is described and gold and silver metal is produced at 48 by known means. Adsorbent is returned to the adsorption tank 40 through a line 50 which includes an adsorption regeneration facility 52.

- Preliminary tests were conducted on a number of concentrates and tailings from various mines to demonstrate that these refractory gold or silver samples were amenable to the bacterial leaching and precious metal extraction stages of the present invention.

- These tests were not designed to yield maximum gold and silver extraction but only to illustrate that bacteria oxidizes these substrates and the precious metal extractions are improved as a result of this preliminary oxidation.

Table 1 gives the results obtained. The heading "Bio-oxidized" means bacterial leach residues treated according to present invention.

- The results of the tests show that the improvement in extraction obtained were high enough

to turn uneconomical ores into commercially viable precious metal mineralizations.

Bacterial Leaching:

The bacterial leach tests were conducted in either 10 litre air-lift pachuca tanks or 8 litre agitated baffled tanks at $34^{\circ}\text{C} \pm 2^{\circ}\text{C}$. Air was sparged underneath the impeller to provide dissolved oxygen and carbon dioxide necessary for bacterial growth. The tests were carried

Table 1. Summary of gold and silver extraction from as-received material and bacterial leach residues by thiourea leaching.

SAMPLE DESCRIPTION	ORE ANALYSIS			THIOUREA EXTRACTION %		
	Au g/t	Ag g/t	S %	As-Received Au	Bio-oxidized Au	Ag
1. Stibnite Arsenopyrite	140	-	15	43	87	-
2. Stibnite Arsenopyrite Pyrite	55	-	24	35	86	-
3. Pyrite, Galena Tetrahedrite	2.5	30	36	25	78	67
4. Pyrite Quartz	6.5	-	18	47	77	-
5. Pyrite Arsenopyrite Pyrrhotite	40	-	24	21	60	-
6. Sphalerite Chalcopyrite	-	89	34	-	22	67
7. Galena Sphalerite Pyrite	-	300	32	-	38	78

- out usually at 10% pulp density, i.e. 900 gram sulphide substrate in 9 litres of liquid in air-sparged pachuca tanks or 600 gram substrate in 6 litres of liquid in stirred tanks. The length of time of agitation and aeration depended upon the type of material being treated and upon the percentage of metals and sulphide sulphur desired to be oxidized from the substrates. The relationship between percentage bacterial oxidation and gold extraction is not necessarily linear and depends on the nature of encapsulation and association of precious metals with the sulphide minerals. In cases where the precious metals are mostly in solid solution, i.e. incorporated entirely into mineral lattice, the above relationship becomes congruous. The leach solution contained appropriate nutrients for bacterial growth and the pH of the slurry was adjusted to 2.0 with sulphuric acid before the introduction of an adapted strain of bacteria.
- The substrate-specific strains were developed by maintaining the bacteria under conditions which promote bacterial growth (i.e. at 35°C and pH 2.0 in sulphuric acid, in the presence of nutrients and aeration) in progressively increasing pulp densities of substrate in question for up to four months.
- The bacterial leaching tests were monitored by periodic measurement of soluble and total metal concentrations and pH. Total metal concentration refers to metal extraction after treatment with 5N hydrochloric acid which solubilizes jarosite and arsenate precipitates. The oxidation-reduction potential of the leach solutions were also noted, though less frequently, with a platinum metal relative to calomel electrode and converted to Eh i.e. vs SHE. The leached residues were decanted in a settling tank and most of the overflow liquor was used for recovery of bacteria.

Gold and Silver Extraction

- Amounts of chemical reagents, typically thiourea or one of the other reagents mentioned above or a combination of the aforementioned lixiviants, were added to the solids containing bacterial leach media for extraction of gold and silver.
- The settled bacterial leach residues were, alternatively, filtered but the solids (filter cake) was not washed prior to being slurried typically in thiourea solution.
- In the final stage of the bacterial leaching circuit, partial or total solid-liquid separation of the leach residues is not pre-requisite for the process of the present invention, since the chemical reagents can be added directly to the bacterial leaching slurry.
- Oxidation of thiourea is affected in the course of gold and silver extraction without deliberate additions. The amount of chemical reagent used is preferably at least 0.01% w/v such as in the range from 0.5 to 35% w/v of the unfiltered leach residue being treated including any liquid added in conjunction with the chemical reagents. Preferably, the amount of chemical reagent is in the range from 0.5 to 10% w/v.
- The solid-liquid separation and/or filtration, however, allows closer control of addition of bacterial leach solution into the gold and silver extraction circuit. This in turn assists to maintain the Eh and pH of the solution within the desired limits. Maintenance of the Eh within certain limits is especially important when thiourea is used as the chemical reagent as will be described. The solid-liquid separation stage also enhances the solid liquid ratio in the gold and silver extraction circuit, typically from 7 to 60 percent w/v solids, and provide means for effective recycle of residual chemical reagent such as thiourea and formamidine disulphide, typically to the start of the gold and silver extraction circuit. Appreciable savings on chemical reagent costs can be achieved by this recycle. The thiourea leaching was always performed below pH 2.0 to minimize oxidative degradation of thiourea. This pH value was conveniently achieved by bacterial oxidation of sulphides to sulphuric acid. The amount of thiorurea added was varied depending upon the Eh of the solution, operation strategies and practical constraints as follows:
- If the arrangement of leach circuit was such that it did not allow effective recycling of the residual chemical reagent, typically thiourea and formamidine disulphide, then the reagent concentration was kept between 0.1 and 5.0 gram thiourea per litre of bacterial leach solution. In the typical Eh value range of bacterial leach solutions, 450–890 mV relative to SHE, 35 to 65 percent of the thiourea was converted to formamidine disulphide. The dissolution rate of gold and silver were relatively rapid, less than three hours, under these conditions and cationic gold and silver complexes could be adsorbed onto particulate or fibrous cloth-type activated carbon or onto strongly acidic cation-exchange resins.
 - If the leach circuit permitted the recycling of residual thiourea and formamidine disulphide, concentration of initial thiorurea can be increased up to 45 gram per litre of bacterial leach solution. Under these conditions, to reduce the thiourea consumption, the Eh of the bacterial leach solution was adjusted to between 350 and 460 mV relative to SHE.
- The reduction of aeration in the final stage of the bacterial leach circuit, increasing the residence time in the solid-liquid separation stage of the leach residues, contacting the bacterial slurry/solution with metals such as iron, zinc, lead or activated carbon with or without the presence of SO₂ or deliberate addition of reducing reagents to lower the valency of ferric ions to ferrous form are among the routes by which the Eh of the pulp can be reduced. Conversely, Eh

can be increased by "stage addition" of high redox bacterial leach solution or by deliberate additions of oxidizing agents such as hydrogen peroxide. The contact time with thiourea in this system was up to six hours. It was found that silver present dissolved initially faster than gold.

- In general, solutions at low thiourea concentrations were more stable with respect to deleterious deposition of sulphur from the reagent degradation. Furthermore, thiourea solutions with higher Eh values were more effective lixiviants for gold and silver extraction from the bacterial leach residues. The stability of thiourea could be increased by controlled addition of bisulphite ion, in the form of sulphurous acid (H_2SO_3), sodium metabisulphite ($\text{Na}_2\text{S}_2\text{O}_5$), sodium dithionite ($\text{Na}_2\text{S}_2\text{O}_4$) or polysulphide compounds. These additions promote reversible formation of thiourea from formamidine disulphide and hence reduce reagent consumption. Active carbonaceous material in the leach residues also catalyze reduction of ferric iron to ferrous form especially in the presence of aqueous sulphur dioxide and/or bisulphite ion.

- Thiourea concentrations were determined by titration with potassium iodate using a starch based indicator, VITEX after acidification with 2N sulphuric acid. Formamidine disulphide concentration was estimated from the difference between the titration value obtained for thiourea directly and that after reduction of formamidine disulphide with zinc metal and sulphuric acid back to thiourea. Aqueous sulphur dioxide and bisulphite interfered with the thiourea analysis. Gold was determined by A.A.S. after destroying the thiourea with aqua regia and extracting the oxidized gold into 1% solution of Aliquat 336 in di-isobutyl-ketone (DIBK). Thiourea and chlorine leach tests were performed in water-jacketed 500 ml multi-neck flasks equipped with pH and redox electrodes, stirrer motor and impeller and a sampling port.

The results of a typical leach test performed on sample 2 (Table 1) were as follows:

The partial chemical analysis of the concentrate is given below:

- | | | | | | |
|----|----|-----------|----|--------------|----|
| 25 | Fe | 17.9 % wt | S | 24 % wt | 25 |
| | As | 11.4 % wt | Au | 55 g/tonne | |
| | Sb | 15.4 % wt | Ag | not detected | |

Bacterial Leaching:

- The bacterial oxidation of the concentrate yielded a typical pattern for low cell inoculum size leaching with the first approximately 350 hours used for the adaption of the bacterial strain to the concentrate. This "lag phase" was followed by rapid dissolution of arsenic and iron and in about 190 hours 9.8 g/litre total arsenic and 7.5 g/litre total iron was oxidized by the bacteria to form solution I. Subsequently the suspended solids were drained and replaced by a fresh bacterial leach medium. This further oxidized the sulphide, to dissolve further arsenic and iron to produce solution II. This procedure generally simulates continuous bacterial leaching. Evidently, arsenopyrite leached preferentially to pyrite and the pH of the solution was lowered to 1.2. This test was not designed to establish the optimum kinetics of the bacterial oxidation of the concentrate. Previous experience with similar concentrates does suggest that residence time for a 17-20% by weight bacterial leach slurry will be in the range of 5 to 8 days.

Table 2. Bacterial Leaching of Concentrate 2

Product	Weight (g) Volume (ml)	Analysis % or ppm Fe As S	Units (g) Fe As	Distribution % Fe As
Head	600	17.9 11.4 24	107.4 68.4	100 100
Residue	390	6.6 6.1 n.d.	25.74 23.79	27.7 36.7
Solution I	6110	6555 5530 -	40.05 33.79	43.1 52.2
Solution II	5920	4575 1215 -	27.08 7.19	29.2 11.1
Calculated Head	600	17.7 12.8	92.87 64.77	100.0 100.0

Upon termination of the bacterial leach, the cumulative pregnant liquor from the first and second stage contained 11.13 g/litre iron and 6.75 g/litre arsenic, yielding cumulative iron and arsenic extractions of 72.3% and 63.3%. The loss of weight from the concentrate was 210 grams during the leach and the resultant residue assayed 6.6% iron and 6.1% arsenic by weight.

Thiourea Leaching.

The results of thiourea leaching tests performed on the as-received concentrate 2 and the corresponding bacterial leach residue are given in Table 3. The bacterial leach residues obtained were divided into representative sub-samples to investigate the effect of a number leaching variables.

The effect of leach temperature on gold extraction from concentrate 2, for example, can be seen from comparison of results in Table 3 with those given below:

		As-Received	Bio-Oxidized
15	Temperature (°C)	18 ± 2	18 ± 2
	Leach Time (h)	6	6
	Weight (g)	75.0	74.10
	Volume (ml)	500	500
	Gold in solution (mg)	0.691	3.835
20	Gold in residue (mg)	3.765	2.723
	Gold extraction (%)	15.5	58.5

Table 3. Thiourea leaching tests on As-Received Concentrate 2 and corresponding Bacterial Leach Residue.

Leaching Parameters	As-Received	Bio-Oxidized
Weight/Volume		
Initial (g/ml)	75.0/500	39.35/400
Final (g/ml)	69.4/496	35.70/375
Leach Solution:		
Temperature (°C)	40 ± 2	40 ± 2
Bacterial Fe ₂ (SO ₄) ₃ (g/l)	5.0	5.0
pH initial	1.65	0.95
pH final	1.98	1.49
Eh initial vs SHE (mV)	839	877
Eh slurry (mV)	490	508
Eh slurry final (mV)	361	392
Thiourea addition (g)	7.50	6.00
Residual thiourea (g)	6.96	5.73
Thiourea consumption (kg/t)	7.2	6.9
Leach time (h)	3	2.5
Gold Analysis:		
Feed head (g/t)	55 ± 5	91 ± 7
Feed head (mg)	4.125 ± 0.300	3.581 ± 0.275
Thiourea residue (mg)	2.794	0.505
Thiourea solution (mg)	1.425	3.191
Calculated head (g/t)	56.3	93.9
Gold Extractions:		
Feed head %	34.5	89.1
Calculated head %	33.7	86.3

It was further noted that above approximately 65°C deleterious decomposition of thiourea to

elemental sulphur was increased considerably.

The Eh of the bacterial leaching solution was decreased from typical values of greater than 780 mV vs SHE to 440–520 mV on addition of thiourea and/or thiourea plus solids. The Eh profile in a particular leach system could broadly be correlated with oxidative degradation of thiourea but thiourea consumption through physical adsorption onto the leach solids could not be predicted and has to be evaluated thoroughly for each sample. In general, up to 80% of physical adsorption of thiourea could be prevented or reversed through use of surface active compounds such as guar, gum arabic, sodium silicate, sodium orthophosphate and depressants such as Aero 633 (a brand name depressant from Cyanamid).

Bacterial Leaching and Gold Extraction by Chlorine:

The concentrate 1 in Table 1 was bacterially oxidized to yield a leach residue assaying 169.2 g/t gold, 2.1% sulphide sulphur and 3.3% elemental sulphur. 25g samples of the bacterial leach residue was treated in a number of 200ml bacterial leaching medium, to which 23.2g of sodium chloride was added, at an initial pH of 1.62. A small stream of chlorine gas was bubbled into the leach vessels and unused chlorine was adsorbed into a unit containing KI solution. 10ml of perchloroethylene was added to the pulp in one leach to study the effect of simultaneous dissolution of elemental sulphur formed in the bacterial leaching stage. The acidity of the leach medium progressively increased during the leach to approximately pH 0.11. Powdered ultra violet stabilized chlorine forming reagents such as sodium dichloroisocyanurate (SDIC) and calcium hypochlorite were also investigated. Stage addition of these reagents were unsuitable substitute for chlorine gas as in all cases gold extractions were less than 25%. Precipitation of metallic gold has occurred in the pulp due to weaker nature of the gold chloride AuCl_4^- complex, as compared with cationic gold thiourea complex. The dissolution with chlorine gas plus perchloroethylene and chlorine gas alone yielded 94.6% and 93.4% extraction of gold in 24 hours; approximately 66% of the gold was extracted within 3 hours in both cases. The chlorine consumption was excessive and estimated at 75kg/t in the presence of perchloroethylene and 83 kg/t without the organic solvent. Further tests are being conducted to reduce the chlorine consumption which was mainly due to antimony chloride formation in the leach suspension.

Gold and silver Recovery from Pregnant Solution

Recovery of gold and silver from the thiourea can be affected in a number of known ways examples of which are summarized below:

35	<i>Thiourea Solutions</i>	<i>Chlorine Solutions</i>	35
i.	Cementation with aluminium and metallic iron	i. adsorption onto activated carbon	
ii.	Adsorption onto activated carbon or strongly acidic cation exchange resins	as metallic gold after removal of free chlorine	40
iii.	Direct electrolysis or electrolysis of eluates from item (ii)	from the liquor, typically with ferrous sulphate or SO_2	
iv.	Gaseous reduction by sulphur dioxide at elevated pressures.		45

It is important to note that rate of adsorption and equilibrium loading of gold onto activated carbon are enhanced three to fifteen fold in acid solutions of the invention as compared with conventional alkaline cyanide systems. Further, in acid solutions, adsorbants of gold, typically activated carbon, is less susceptible to "fouling" with invaluable components in the leach solution.

Modifications and variations such as would be apparent to a skilled addressee are deemed within the scope of the present invention.

55 CLAIMS

1. A process for the extraction of gold and/or silver from a particulate auriferous or argentiferous sulphide containing substrate which comprises contacting the substrate with an acidic aqueous leach medium containing an aerobic sulphide-oxidizing bacteria so as to oxidize at least a portion of the sulphide to sulphate, and then contacting the oxidized substrate with a chemical reagent in an aqueous medium so as to dissolve gold and silver present in the oxidized substrate.

2. A process according to claim 1, in which the chemical reagent is thiourea.

3. A process according to claim 1, in which the chemical reagent is thiourea, chlorine, hypochlorite, chloride, thiosulphate or thiocyanate or a combination thereof.

4. A process according to any one of the preceding claims, in which the bacteria is an

- adapted strain and the process is conducted in slurry suspension having a pH not less than 0.7.
5. A process according to claim 4, in which the bacteria is predominantly autotrophic.
6. A process according to any one of the preceding claims, which is conducted at a temperature in the range from 5 to 40°C
- 5 7. A process according to claim 6, which is conducted at a temperature in the range from 27 to 37°C. 5
8. A process according to any one of the preceding claims, in which the substrate has a particle size of less than 500 microns.
9. A process according to claim 8, in which the substrate has a particle size of less than 74 10 microns. 10
10. A process according to any one of the preceding claims, in which the acidic aqueous leach medium containing the substrate preferably contains initially from 10 to 40% by weight solids.
11. A process according to any one of the preceding claims, in which the acidic aqueous 15 leach medium is aerated to supply oxygen and optionally carbon dioxide for the bacterial leaching process. 15
12. A process according to any one of the preceding claims, in which the acidic aqueous bacterial leach medium has a pH in the range from 1.3 to 2.7.
13. A process according to any one of the preceding claims, in which a portion of the 20 aqueous bacterial leach medium is separated off from the main body thereof, the solids content of the separated portion is settled, the liquor is removed from the settled solids, the removed liquor is subjected to partial neutralization to a pH up to 4.0 by addition of alkaline material, to form precipitated material which is separated from the removed liquor and the partially neutralized liquor and medium. 20
14. A process according to claim 13, in which the removed liquor is adjusted to a pH in the 25 range from 2.75 to 2.95. 25
15. A process according to claim 13 or 14, in which the removed liquor is partially neutralized in first and second stages, the first stage being to produce a precipitate containing predominantly jarosites and arsenates and the second stage being to produce a precipitate containing 30 predominantly gypsum, the precipitates being separated from the removed partially neutralized liquor. 30
16. A process according to any one of the preceding claims, in which the chemical reagent is dissolved in the bacterial leach medium.
17. A process according to any one of claims 1 to 15, in which the bacterial leach medium 35 is filtered and the chemical reagent in dissolved form is contacted with the resulting filter cake. 35
18. A process according to any one of the preceding claims, in which the amount of chemical reagent used is from 0.01 to 35% w/v of the composition resulting from contacting of the chemical reagent with material from the bacterial leach medium.
19. A process according to claim 18, in which the amount the settled solids are returned to 40 the main body of the bacterial leach of chemical reagent used is from 0.5 to 10% w/v of the composition resulting from contacting of the chemical reagent with material from the bacterial leach medium. 40
20. A process according to any one of the preceding claims in which the solids content in the gold and silver extraction stage is from 10 to 70% w/v, preferably from 35 to 50% w/v.
- 45 21. A process according to claim 2, in which the pH of the gold and silver extraction medium is maintained below 2.0. 45
22. A process according to claim 21, in which the Eh of the gold and silver extracting medium is maintained at at least 300mV, preferably from 350mV to 890mV, relative to SHE.
23. A process for the extraction of gold and/or silver comprising contacting a bacterially 50 leached substrate with a chemical reagent in an acidic medium substantially as hereinbefore described. 50